Study on Defects of Large-sized Ti/Steel Composite Materials in Explosive Welding

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Abstract

In this paper, the dynamic process of explosive welding for large-sized plates is studied by numerical simulation. Folding deformation could be found during the process of explosive welding based on the studies on the morphological changes of the flyer plate at different time. The calculation results are in good agreement with the practical projects. The study shows that folding deformation is a crucial problem which should be noticed in the process of explosive welding, and the reasons for folding deformation are discussed in the paper. The conclusion can give reference for the development of explosive welding technology.

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1. Introduction

Explosive welding is a kind of welding technology that can combine a flyer plate with a base plate by great pressure, which is produced by detonation. This energy is aimed to push the flyer plate moving fast and then colliding obliquely with the base plate\textsuperscript{[1]}. The experimental investigation of explosive welding becomes difficult because of the instantaneous and the complexity of the explosion process\textsuperscript{[2]}. In addition, the development of this theoretical research is also hindered by the indetermination of the influencing factors of many phenomena appearing in explosive welding. In practical project, the welding defects of large-sized plates are especially serious so that the welding quality cannot meet the standards, and a second explosive welding is often needed for repairing these defects. More and more scholars are

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searching for the methods of solving the sealing-off problems both in the theoretical and experimental ways. For example, by considering the influence of superposition and diffraction of the detonation waves, boundary effects \(^3\), reflected tension waves in free boundaries and the exhaustion of air in large-sized flyer plates \(^4\), many experiments with different parameters have been carried out. All these experiments are aimed at promoting the quality of explosive welding in large-sized flyer plates, but defect zones are still. So some other important factors affecting the quality of welding and the corresponding solutions are waiting for a further study. What’s more, because of the limitations of experimental investigations, the study on numerical simulation becomes an important way for those difficult problems. Because explosive welding is a cross-fields science, the impact mechanism of the involved parameters is very complex, it is necessary to build a right numerical model of explosion welding for researching the impact of various parameters on explosive welding.

This paper studies the reasons for the welding defects of large-sized Ti/Steel composite plate. The dynamic process of the explosive welding can be visually displayed by numerical simulation. During the process of explosive welding, the phenomenon of folding deformation is discovered based on the morphological changes of the flyer plate, and the impact on explosive welding quality is studied. At last, some reasons for the occurrence of folding deformation are analyzed.

2. Numerical simulation method of explosive welding

The explosive welding numerical model including air and soil layers shown in figure 1 is established by finite element software ANSYS/LS-DYNA according to the actual process of explosive welding of large-sized Ti/Steel composite plate. The interaction between soil and base plate is considered in addition to the collision and contact between flyer plate and base plate in the model.

Explosive welding involves explosive blasting, mechanical impact, high-temperature melting and solidification welding and so on. It is difficult to establish an explosive welding model according with the realistic process. Therefore, Johnson-Cook (JC) model and Jones-Wilkins-Lee (JWL) model based on the appropriate assumption and the mathematical simplification are frequently adopted to describe the metal forming and the detonation of explosive welding \(^5,6\).

Constitutive relation of titanium and steel can be described by Johnson-Cook model \(^7\):

\[
\sigma_y = \left( A + B e^{\varepsilon^p} \right) \left[ 1 + C \ln \left( \frac{\dot{\varepsilon}^p}{\dot{\varepsilon}_0} \right) \left( 1 - T^* \right) \right]
\]

(1)

Where \(\sigma_y\), \(\varepsilon^p\), \(\dot{\varepsilon}_0\) and \(T^*\) are, respectively, the Von Mises flow stress, the effective plastic strain, effective total strain rate and the homologous temperature, and \(A, B, C, n\) and \(m\) are input constants. The model can describe material large strain under the condition of high velocity impact and explosion effect,
mechanical properties under the condition of high strain rate and high temperature, strain rate hardening and temperature soften effect.

The relationship between pressure and volumetric strain of the explosive can be described by JWL material model [8]:

\[
P = A_1 \left( 1 - \frac{\omega}{R_1 V} \right) e^{-\omega V} + B_1 \left( 1 - \frac{\omega}{R_2 V} \right) e^{-\omega V} + \frac{\omega E_0}{V}
\]

Where \( P, E_0, \) and \( V \) respectively denote the pressure of detonation products, the internal energy and the relative volume, and \( A_1, B_1, R_1, R_2 \) and \( \omega \) are input constants.

Hexahedral element solid164 is used for this model, of which all boundary conditions are taken considering the penetration contact of welding process bearing high velocity impact of large strain rate. In the process of stress wave propagation, the absorption of stress wave is considered in the border of air-layer model, and the reflection of stress wave is default in the border of solid model. As the same as the practical process of explosive welding, the explosive is detonated at the central point in the numerical simulation.

3. Numerical simulation results and analysis

Fig.2 shows the top view of flyer plate folding deformation of large-sized Ti/Steel composite plate in explosive welding process. The flyer plate edge is cut by base plate because of explosive impact loading, and the arc curve expresses the position of detonation wave at this moment.

As shown in fig.2, the flyer plate folding deformation experiences three stages of occurring, developing and disappearing. Fig 2(a) shows that at the early stage of explosive welding, the condition of
flyer plate is stable, and the welding quality in middle regional of the large-sized plate is perfect. When the detonation wave transfers to the position, as shown in figure 2(b), folding deformation is available at the boundary of the long side of flyer plate. Figure 2(c) shows that the depth of folding deformation increases and the affecting area enlarges continuously with the detonation wave development. Figure 2(d) shows that the folding deformation disappears gradually as the explosive welding goes on. In fig. 2, the whole process of folding deformation is shown clearly in the explosive welding process of large-sized composite plates.

The paper gives a possible reason for welding defect on the boundary by numerical simulation. The calculation results are in good agreement with the practical experiments. The result shows that the undulate folding deformation can be found in specific location of flyer plate during the process of explosive welding. Because of the folding deformation, the air in the space layer can’t be discharged completely, which leads to the welding defects. The reasons for folding deformation are related to the material properties of flyer plate, the way of detonation and the size of plates. First, Ti has a good performance in the ductility so that a greater plastic extended deformation can be found through the direction of detonation. Second, the explosive is generally detonated at the central point in the explosive welding of large-sized plates, so the extended deformation of flyer plate develops progressively in different directions with the mid-point initiation as the center, which leads to the uneven longitudinal deformation in the same cross section. Third, the cumulative deformation of flyer plate is the cause of folding deformation. If the plate is small, the folding deformation is not perceptible, so it is an essential condition of folding deformation that plates are large enough.

4. Conclusion

(1) The range of welding defect found by numerical simulation is in good agreement with the practical projects, which shows that the numerical model in this paper can well simulate the dynamic process of explosive welding.

(2) The study shows that there is folding deformation of flyer plate during the process of explosive welding. Folding deformation effect, which is an important reason for welding defects occurring in large-sized plates, is put forward in the paper. The cause of folding deformation is related to the material properties of flyer plate, the way of detonation and the size of plates.

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